North Miami-Dade County

Ground Water Flow Model

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Preface

The purpose of this report is to document the development of the north Miami-Dade County ground water flow model. In particular, it is intended to serve as a means for assisting experienced engineers and hydrogeologists proficient in the use of MODFLOW in familiarizing themselves with the model. It is not, however, intended to serve as a user's manual for applying the model. Furthermore, it should be emphasized that only the development process is presented herein. Previous or current applications of the model are discussed in separate reports.

The main text is divided into five parts: Introduction and Purpose, Description of Physical Facilities, Initial Model Construction, Model Calibration, and Conclusions and Future Improvements. In addition, there are seven accompanying appendices that contain information regarding supporting databases, sensitivity analyses and calibration results. The first section presents the purpose and primary objectives of the initial model applications that necessitated the development of the model. The second part provides an overview of the predominant features that influence the ground and surface water hydrology within the model domain. The third section discusses the initial model setup and the manner in which the hydrologic features presented in section two were incorporated into the model. This section is supplemented by appendices A - C which contain detailed discussions on the GIS database, the hydrologic database and other data used to construct the model. Part four contains an exposition of both the steady state and transient calibration processes as well as the sensitivity analyses completed as of the current date. Relevant details are provided in appendices D and E. Finally, part five outlines the limitations of the model in its current state along with some recommendations for future improvements.

In addition to the information presented above, several other important facts should be emphasized. First, as is (or, at least, should be) the case with most hydrologic models, attempts will be made to continually improve the model presented here. Such improvements may strictly involve the rectification of the types of limitations mentioned in section 5 or, on the other hand, could consist of significant changes needed to support future applications. In any case, this publication will be updated to reflect such changes. Any updates to either the model or this report will be documented in an accompanying revision summary report.

It is intended that this model will continue to serve as a useful tool in water resources planning, water use permitting, the engineering design of regional water supply projects and other efforts related to Everglades restoration and water resource management in southern Florida. Any comments or questions related to either this report or the model itself are welcome and may be forwarded to the following individual:

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1 Introduction and Purpose

1.1 Background

The North Miami-Dade County ground water flow model, also sometimes referred to as version 3.0 of the Lake Belt ground water flow model, is the third in a series of ground water flow models developed for applications in northern Miami-Dade County. The first, version 1.0 of the Lake Belt ground water flow model (Wilsnack, 1995), was developed in support of the initial version of the Lower East Coast Regional Water Supply Plan. The second, version 2.0 (Wilsnack, et. al., 1997; Wilsnack and Nair, 1998), was developed in support of the Northwest Dade County Freshwater Lake Plan (SFWMD, 1996). These two older versions of the model are no longer used by the District and are superceded by version 3.0. This current version is the first to include capabilities for simulating certain key surface water processes and was developed in support of both the Comprehensive Everglades Restoration Plan (CERP) and the Lower East Coast Water Supply Plan.

1.2 CERP and Lower East Coast Water Supply Plan

Among the many facets of the CERP (Comprehensive Everglades Restoration Plan), authorized by the United State Congress in 1992, is the Water Preserve Area (WPA) Hydrologic and Hydraulic Analysis. One of the primary focuses of this project is the high resolution hydrologic modeling and conceptual design engineering work needed to plan, site, design and evaluate the numerous proposed structural improvements to southern Florida's surface and ground water management systems. These improvements include, but are not limited to, reservoirs, stormwater treatment areas, canal improvements, seepage barriers and water control structures. To support such an effort, five high-resolution ground water flow models with surface water components were developed for the lower east coast service areas. Each of these models simulates ground water flow within the surficial aquifer system, overland flow in regional wetlands and surface reservoirs, and, where applicable, interactions of mining quarries with ground water.

The Lower East Coast Water Supply Plan (LECWSP) was initiated by the Florida Water Resources Act, Chapter 373, Florida Statutes. Like the WPA analysis, the primary goals and objectives of the LECWSP include the conceptual design and evaluation of numerous structural improvements to the regional water management system within the lower east coast service areas. Additionally, this plan also addresses the impacts and benefits of various nonstructural water supply alternatives such as changes to the operational procedures for municipal wellfields.

1.3 Modeling Objectives

An evaluation of water supply improvements based on hydrologic models is necessarily made relative to both current and future base conditions (i.e. "as-is" with no improvements). Additionally, the ability of hydrologic models to assess the benefits and impacts of the proposed improvements is usually realized through the systematic use of selected performance measures.

Examples of such performance measures would include, but not be limited to, stage-duration curves for wetlands and reservoirs, ground water level hydrographs and ground water flow across selected boundaries. In the evaluation of structural water supply alternatives for the LECWSP and WPA analysis, assessments of the benefits and impacts of proposed improvements were carried out by first constructing performance measure based graphics from the model output of each type of scenario simulation (i.e. current base, future base, and various future improved) and then comparing the graphics across the simulations.

2 Description of Physical Features

2.1 Hydrogeology and Hydrostratigraphy

Only the surficial aquifer system was included in the north Miami-Dade County model. The surficial aquifer system within northern Miami-Dade County essentially consists of (in order of increasing depth): shallow sediments; the Miami Limestone (formerly referred to as the Miami Oolite); the Fort Thompson formation (which includes the Biscayne aquifer); the upper semi-confining unit of the Tamiami formation; the Gray Limestone aquifer; and the lower clastic sediments of the Tamiami formation. Deviations from this general sequence of units, however, can occur in the extreme eastern and western portions of the model domain. A comprehensive overview of and some detailed discussions on the surficial aquifer system within northern Miami-Dade county are provided by Fish and Stewart (1991). In addition, a number of new core borings and geophysical logs were acquired and analyzed during recent years by District staff. These data, data published in Fish and Stewart (1991) and various unpublished data were all used to construct the geologic database needed to support the model development. For additional information on this effort, see Switanek (2000).

2.2 Surface Water Management Systems

The predominant canal network within the northern Miami-Dade County model domain is shown in figure 2.2.1. Included are all or portions of District canals C-1W, C-1N, C-2, C-3, C-4, C-5, C-6, C-7, C-8, C-9, C-10, C-11, the C-100 canals, C-123, C-304, L-29, L-30, L-31N, L-33, L-67A and L-67EXT. In addition, numerous secondary canals owned and operated by Miami-Dade DERM are contained within the model domain. This includes the Northwest Wellfield protection canal system. Water levels in all of these canals are controlled and maintained by a network of District and DERM water control structures (figure 2.2.1). Shown also in figure 2.2.1 are the approximate drainage areas of the District canals located east of the water conservation areas. Located within most of these basins are tertiary canal networks as well as stormwater best management practices that provide drainage to urban areas.

There is a strong degree of hydraulic interaction between these canals and the surficial aquifer system. This has been identified in previous investigations within the region by Fish and Stewart (1991), Merritt (1995), and Cooper and Neidrauer (1989).

2.3 Regional Wetlands

The regional wetland systems located either partially or wholly within the model domain include water conservation areas (WCA) 3A and 3B, the Everglades National Park (ENP), the Pennsuco wetlands and the Bird Drive wetlands. WCA 3A encompasses an area of 767.3 square miles and lies within western Broward and northwestern Miami-Dade counties. The predominant vegetation is sawgrass with tree islands. Its functions include: 1) water supply storage, 2) flood control storage, and 3) the regulation of flow between Lake Okeechobee, the Everglades National Park, and the Miami Metropolitan area.

WCA 3B encompasses an area of 153.6 square miles and lies within south-central Broward and north-central Miami-Dade counties. The predominant vegetation is sawgrass. Its functions include: 1) water supply storage, 2) flood control storage, and 3) controlling the transfer of water to the ENP from Lake Okeechobee and WCA 3A. Also, the location of WCA 3B is important to Biscayne aquifer recharge since leakage from the eastern portion of WCA 3B helps to maintain groundwater levels in coastal areas to the east. Adequate groundwater levels are necessary for the management of the municipal wellfields as well as the prevention of salt-water intrusion. Some of the leakage from WCA 3B, however, is intercepted by the borrow canals aligned along its eastern border.

The ENP basin is a natural basin set aside to preserve a portion of the original Everglades. It has an area of 1684.5 square miles, and is made up of freshwater sloughs, sawgrass prairies, wet prairies, mangrove forests, and saline tidal areas at the south end of the Florida peninsula. It is located in western Dade County, in northwest Monroe County, and in southwest Collier County. The ENP basin includes all of Everglades National Park, the East Everglades area, and a part of the south unit of the East Everglades Wildlife Management Area. The ENP provides ecological, water storage, flood control, and recreational benefits as well as wildlife habitat. For additional information on the ENP or water conservation areas, see Cooper and Roy (1991).

The Bird Drive Basin (BDB) is a 12.5 square mile area of freshwater wetlands located in central Miami-Dade county. Soils are typically a few inches to 3 feet of peat organic soils over dense limestone, and the vegetation is predominantly wetland prairie. The BDB provides flood control and water quality benefits. All of the BDB is underlain by the Biscayne aquifer, the sole source of drinking water in Miami-Dade County. Furthermore, it has several characteristics that enable it to play an important role in aquifer recharge. First, it has a permeable surface with a high infiltration rate that allows surface water to reach the aquifer. Second, it is surrounded by levees and higher ground which nearly eliminates surface water runoff from the basin. For additional information on the ecological and hydrologic characteristics of the BDB, see Richter, et. al. (1990).

The Pennsuco wetland is a 20 square mile area directly north if the BDB. The vegetation is predominantly sawgrass with various tracts of land infested by melaleuca. This area is important is important in maintaining adequate groundwater conditions for the adjacent wellfields.

2.3 Mining Quarries

The region within northern Miami-Dade County commonly known as the “Lake Belt” is depicted in figure 2.3.1, where the January, 1994 mining configuration is illustrated. Located within this area are numerous limestone mining quarries that typically range from about 30 feet to 80 feet in depth. As of 1996, an additional 300 – 400 acres of mines were being excavated each year (SFWMD, 1996).

These quarries can generally be characterized as having very steep (nearly vertical) side walls that are in direct contact with the aquifer. Additionally, the quarry bottoms typically contain several feet of fine sediments resulting from mining operations (Paul Larsen, personal communication, 1996).

2.4 Water Use

Most of the ground water withdrawals in northern Miami-Dade County are for public water supply purposes and occur at the wellfield locations shown in figure 2.4.1. Pumpage for golf course irrigation and local domestic supplies also occurs at various locations. The primary source of public water supplies in this region is the Biscayne aquifer, although withdrawals from the Gray Limestone aquifer also occur at certain wellfields located within the western portions of the model domain(e.g. the Northwest Wellfield)**.** Surface water is currently not used for water supply purposes.

Listed below are the five major water treatment facilities located in the northern Miami-Dade county. These range in size from the 9 MGD (Winson facility) to 225 MGD (Alexander Orr Jr. facility).

1. Winson (City of North-Miami)
2. Norwood Oeffler (City of North Miami Beach)
3. Hialeah (Miami-Dade Water and Sewer Department)
4. Preston (Miami-Dade Water and Sewer Department)
5. Alexander Orr Jr. (Miami-Dade Water and Sewer Department)

Water use in the southern Broward county area is less centralized than northern Miami-Dade County. The primary users include:

1. Seminole reservation
2. Hollywood City
3. Miramar City
4. Davie Town
5. Pembroke Pines City
6. Hallandale City
7. Broward 3A, 3B and 3C
8. Dania City
9. Cooper City
10. South Broward Utilities

3 Initial Model Construction

Given the model objectives discussed in section 1 along with the hydrogeologic, wetland and surface water management systems described in section 2, an initial version of the model was constructed. The major components of the model are described in the sections that follow.

3.1 Model Code and Grid Design

3.1.1 General Features of the U.S.G.S. Modeling Code MODFLOW

One of the subsequent steps that occurs early in the model development process is the selection of a model code that can meet the model development and application objectives. The USGS code MODFLOW was selected for this purpose for the following reasons:

- It has been widely accepted in the ground water modeling profession for over ten years;
- The code is well documented and within the Public Domain;
- The code is readily adaptable to a variety of ground water flow systems;
- The modular structure of the code facilitates any modifications required to enable its application to the types of unique ground water flow problems encountered in southern Florida.

3.1.2 Model Grid

The spatial limits of the finite-difference grid for this model are shown in figure 3.1.1. The spatial coordinates shown were selected so as to align the cells of this grid with those of an adjacent, overlapping model located immediately to the north. Horizontally, all of the cells are square with a dimension of 500 feet. While the resolution of this grid may seem somewhat excessive in relation to its spatial extent, the benefits derived from selecting such a fine resolution include, but are not necessarily limited to:

- better accuracy of computed water table drawdowns near wellfields;
- increased accuracy of base flows to canals;
- more accurate representations of mining quarry planforms;
- a reduced likelihood that two features of interest will occupy the same cell (useful for regulatory applications);
- an improved capability for incorporating complex structural improvements into the model.

3.2 Ground Water Flow System

3.2.1 Vertical Discretization

The surficial aquifer system within the model domain was divided into eight layers as depicted in figure 3.2.1. This essentially represents a strict finite-difference based discretization in the vertical direction as opposed to the conventional stratigraphic type of vertical discretization. Given the high degree of uncertainty and variability inherent to the hydraulic properties of the surficial aquifer system, it was felt that this layering scheme was a legitimate alternative. As can be seen in figure 3.2.1, the top of the first aquifer layer was set at 0.0 feet NGVD where the wetland layer is active and land surface elsewhere. The reasons for this will be discussed in the next section. In addition, setting the bottom elevation of the uppermost aquifer layer to –10 feet NGVD allows this layer to encompass most of the canal cross sections within the model domain. Dividing the rest of the surficial aquifer system into the layers shown makes it more convenient to account for varying lake depths in the model.

3.2.2 Aquifer Parameters

3.2.2.1 Hydraulic Conductivity

Figure 3.2.2 shows the locations of the geologic control wells used to develop point estimates of hydraulic conductivity within each model layer. At each of these wells, a hydraulic conductivity range was assigned to each distinct lithologic interval using a methodology established by Fish and Stewart (1991) (see Switanek, 2000). The actual hydraulic conductivity value assigned to each lithologic unit was the logarithmic mean of the minimum and maximum values for the range. In cases where pump test results were available, the test results were assigned instead of the estimated hydraulic conductivity values to those lithologic units within the tested interval.

The hydraulic conductivity values assigned to the various lithologic units were used to compute a mean horizontal hydraulic conductivity within each layer at each control well (where adequate data existed). The resulting point values of hydraulic conductivity were used to estimate horizontal hydraulic conductivity within each layer over the model domain. For numerical stability purposes, hydraulic conductivity values were capped at 25,000 ft/day.

Given the level of uncertainty associated with assigning hydraulic conductivity values to the various lithologic units along with the high degree of uncertainty inherent to the magnitude and orientation of secondary porosity within each unit, an anisotropic ratio of 1:1 was assumed to exist within each distinct lithologic zone at each well. This assumption along with a procedure similar to the one described above were used to estimate values of vertical conductance (Vcont) between the midpoints of each model layer.

3.2.2.2 Specific Yield and Storage

Data on specific yield for the surficial aquifer system within the model domain are substantially more sparse than those for hydraulic conductivity. Table 3.2.1 lists several reported values along with their general locations. It should be pointed out that some of these data may have been obtained from the same sources by the various investigators. Based on this information, a constant value of 0.2 was used in the initial version of the model except at locations of urban development lakes, where specific yield was increased to a maximum value of 1.0 to account for the increase in storage volume.

A value of 10^{-6} ft^{-1} was applied everywhere for specific storage. This value was derived from both the physical properties of water and limestone. Details on the derivation of this value are provided in appendix C.

Table 3.2.1. Specific Yield Data for the Surficial Aquifer System

Source	General Location	Specific Yield
Report of Investigations #4 (Parker, et.al.,1944)	Miami Area	0.18
Report of Investigations #24, Part 2 (Sherwood & Leach, 1962)	C-2 Basin	0.11
	Miami Area	0.2
Report of Investigations #24, Part 3 (Leach & Sherwood, 1963)	Eastern C-9 Basin	0.1, 0.2
Report of Investigations #17 (Schroeder, et.al., 1958)	Miami Area	0.1 – 0.35

3.3 Wetland Flow System

3.3.1 Characterization of Overland Flow

Flow within the wetland layer was modeled using the Wetlands package of MODFLOW (Restrepo, et.al., 1998). The methodology employed by this package for simulating overland flow is based on the following relationship between discharge per unit width, flow depth, hydraulic gradient and hydraulic conductance of the wetland:

$$q = K_w h^{\beta} S_f^{\alpha} \tag{3.3.1}$$

Where

- q = the discharge per unit width (L^2/T)
- h = the flow depth (L)
- S_f = the hydraulic gradient
- K_w = the hydraulic conductance coefficient for overland flow ($L^2/T/L^{\beta}$)
- β = an exponent related to microtopography and the stem density-depth distribution
- α = an exponent that reflects the degree of laminar or turbulent flow conditions

Equation 3.2.1 represents a formulation used in earlier investigations of overland flow in wetlands. Examples of this can be found in Kadlec(1990), Hammer and Kadlec (1986), and Chescheir, et.al. (1987).

While the form of equation 3.2.1 appears intuitive, little was known at the beginning of the model development process about the relationship of the parameters $K_{w,}$ β and α to the various types of wetland cover found within the model domain. Table 3.3.1 provides values of $K_{w,}$ β and α cited by Kadlec (1990) for various wetland environments found in Michigan and eastern North Carolina. Also shown are values for certain turf grasses. Kadlec (1990) indicates that that the values of $K_{w,}$ β and α are not independent but, rather, the value of K_w is contingent upon the choice of values for β and α. Despite the sparse nature of these data, it is interesting to note that the reported values of β and α for the field investigations appear to be consistently equal (or close) to 3.0 and 1.0, respectively. A second important observation is that K_w tends to be on the order of 10^8 ft^2/day/ft$^\beta$ for the same investigations regardless of the experimental site location. All of this suggests that setting $K_w = 10^8$ ft^2/day/ft$^\beta$, $\beta = 3.0$ and $\alpha = 1.0$ would provide a good starting point for model development. However, as will be explained in a later section, numerical difficulties can result when a value of K_w this large is used. Consequently, a value of $K_w = 10^6$ ft^2/day/ft$^\beta$ was applied to those wetland areas with the sparsest vegetation while values reduced by a specified percentage were applied to wetland areas covered with more dense vegetation. The resulting relationship between K_w and SFWMD level 3 land use code (used to map the different types of wetland vegetation) is shown in table 3.3.2.

Table 3.3.1. Experimental Values of $K_{w,}$ β and α Cited by Kadlec (1990)*

Source	Location	K_w (ft^2/day/ft$^\beta$)	β	α
Kadlec (1990)	Houghton Lake, Michigan	87×10^8	2.5	0.7
Kadlec, et.al. (1981)	Houghton Lake, Michigan	1.2×10^8	3.0	1.0
Hammer and Kadlec (1986)	Houghton Lake, Michigan	2×10^8	3.0	1.0
Chescheir, et.al. (1987)	Eastern N.C.	7.9×10^8	3.0	1.0
Chen (1976)				
Kentucky Blue Grass	Laboratory	228×10^8	3.75	0.50
Bermuda Grass	Laboratory	65.6×10^8	3.75	0.39

* Published values of K_w were converted from SI units to the English units shown

3.3.2 Wetland-Aquifer Interactions

As depicted in figure 3.2.1, the model layer representing the regional wetland flow systems includes the overland flow regime combined with both the organic soil layers and the underlying geology down to an elevation of 0 feet NGVD. This includes most or all of the Miami limestone and, in certain locations, may also include upper portions of the Fort Thompson formation. The reason for incorporating this zone into the wetland flow layer of the model was to avoid the numerical difficulties associated with the drying and rewetting of model cells within this layer.

Table 3.3.2. Relationship Between Vegetation Type and Hydraulic Conductance Coefficient

Land Use Code	K_w ($ft^2/day/ft^{\beta}$)
WN, WNCT, WNWL, H	1,000,000
WF, WFCY, WFM1, WFM2, WFM3, WFM4, WFME, WFMX, WFSB, WS, WSRM	300,000
WNSG, WXCP, WXHM, WXPP	700,000

Wetland cells could become dry and require frequent rewetting if the wetland layer consisted solely of the overland flow regime.

When establishing a bottom elevation for this wetland layer, preference was given to a representative depth to the interface between the Miami limestone and the Fort Thompson formation. The Miami limestone is generally much less permeable than the underlying Fort Thompson formation and can be conceptualized as being part of a somewhat restrictive unit situated between the ponded surface water in the wetlands and the ground water flow system within the Fort Thompson formation. In particular, previous studies have revealed the existence of shallow and dense limestone layers at various locations within the western portions of the model domain where regional wetland systems exist (see, for example, Klein and Sherwood, 1961; Schroeder, et.al., 1958; Fish and Stewart, 1991). Krupa (1997) reviewed nearly all of the previous investigations along with recent investigations by District staff and concluded that, within the wetland areas, the Miami limestone contains an arealy extensive (although discontinuous) layer of dense limestone. Similarly, dense limestone layers can exist within upper portions of the Fort Thompson formation. It is interesting to note that the data compiled during this effort suggest that this restrictive layer within the Miami limestone often occurs in the vicinity of 0 feet NGVD. Consequently, the bottom of the wetland layers was set at this elevation for modeling purposes.

Given this conceptualization of the retardant zone between the overland flow regime and the primary ground water flow system, horizontal hydraulic conductivity (HYMUC), anisotropic ratio (VHYMUCR) and specific yield are the hydrogeologic parameters of this shallow aquifer zone needed by the Wetlands module to simulate flow in the wetland layer. Values of HYMUC and VHYMUCR were computed at those wells with adequate data within this zone using a procedure similar to the one described previously. As before, the resulting point values were used to estimate values at each model cell. A similar procedure was used to estimate the anisotropic ratio within the top aquifer layer (VHYLY2R). This parameter along with VHYMUCR is used by the Wetlands module to compute vertical conductance between the wetland and top aquifer layers. Specific yield was set to a constant value for both the shallow geologic zone (0.2) and the surface water regime (0.9).

3.3.3 Wetland System Boundaries

The wetland systems that were incorporated into the wetland layer of the model are illustrated in figure 3.3.1. As discussed earlier, these include WCA 3A, WCA 3B, the portion of the ENP lying within the model domain, the Pennsuco wetlands, the Bird Drive wetlands and the wetland areas located between the Dade-Broward levee and either the Florida Power and Light access road or the western boundaries of adjacent urban areas.

3.4 Land Surface Elevation

The land surface Digital Elevation Model (DEM) for the model region was constructed from the data sources provided in table 3.4.1 and shown in figure 3.4.1.. Also indicated is the geographic region corresponding to the location of each data source.

The NGS benchmarks provided elevation data referenced to both the NGVD 29 and NAVD 88 vertical datums. Elevations referenced to the NAVD 88 datum points were converted to the NGVD 29 datum using the VERTCON (NGS Version 2) program. These benchmark elevations can be recessed below, projected above, or flush with ground level (Sosnowski 1995). Only benchmark elevations that are flush with land surface, or could be corrected so as to be flush with land surface, were used.

The Beadman survey was completed during the early 1990’s by Beadman and Associates in conjunction with the District. This survey covered most of the Lake Belt area, the Pennsuco wetlands, the Bird Drive recharge area and the northeast corner of the Everglades National Park. The vertical datum referenced was the NGVD 29.

The U.S. Army Corps of Engineers and USGS survey of WCA-3B (1995) employed Kinematic, On-The-Fly (OTF) Global Positioning System (GPS) units along with airboats equipped with dual base. The survey covered most of WCA-3B in a grid pattern with a spacing of about ¼ mile and included about 2100 point measurements. In particular, tree islands were located by recording at least four points that described the length and width of the features. As in the NGS survey, elevations referenced the NAVD 88 vertical datum and were converted to the NGVD 29 vertical datum using the VERTCON program.

The U.S. Army Corps of Engineers 1960 topographic survey contour data were applied to those areas within WCA-3A that were not covered in the more recent surveys. In this case, it was assumed that the portion of WCA-3A within the model domain was not affected by the subsidence due to peat oxidation that was evident in WCA-3B.

The USGS quad sheets with spot elevation data were used for certain areas within southern Broward county. The elevations were surveyed by the USGS in the late 1960's and were referenced to the NGVD 29 datum. Spot elevation points located near man made features were avoided in order to allow the DEM to better represent ambient land surface elevations.

Table 3.4.1. Data Sources for Land Surface Elevation.

Source	Area
surveyed land surface elevations at USGS observation wells	Urban areas of northern Miami-Dade and southern Broward counties
National Geodetic Survey (NGS) benchmark elevations	Urban areas of northern Miami-Dade and southern Broward counties.
Beadman and Associates	Pennsuco wetlands, Lake Belt area and Everglades National Park
U.S. Army COE, USGS (1995)	Water Conservation Area 3B.
U.S. Army COE (1960)	Northwestern portion of the model domain inWCA-3A.
USGS Quad Sheets (1960)	southwestern Broward county

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3.5 Canals

3.5.1 Canal Classifications

The interactions between ground water and canals were modeled using the River and Drain packages. It should be emphasized here that most, if not all, of the canals within the model domain do not adhere strictly to the definition of a "river" that is inherent to MODFLOW. This is essentially due to the fact that, as discussed previously, canal stages and ground water levels within this region are often highly interdependent while the MODFLOW based conceptualization of a river assumes that canal stages are independent of ground water levels and remain constant over a given stress period. However, if a relatively short stress period length is used, the use of the River package in this type of environment will generally yield acceptable results.

Figure 3.5.1 shows the canal classifications (i.e. either “river” or “drain”) used in the model. Canal reaches were classified as a “drain” when they were either bound between an upstream terminus and a downstream control structure or it was evident that they did not carry enough flow to provide significant amounts of recharge to the aquifer. Otherwise, canal reaches were classified as “rivers”.

3.5.2 Conceptual Cross Section

The use of either the River or Drain package requires as input a conductance parameter that reflects the head losses incurred by flow between the canal and the aquifer. For a given canal reach, this conductance parameter should reflect the wetted perimeter of the channel as well as the properties of the sediment bed located along the canal aquifer interface (McDonald and Harbaugh, 1988). In particular, the conductance terms input to the model were formulated using a conceptual canal cross section with trapezoidal geometry, side walls that are nearly in direct connection with the surrounding aquifer, and a sediment bed covering the bottom. Here, some head loss through the canal side walls is assumed to occur through a thin sediment layer. The basis for this conceptualization and the methodology used to compute the resulting values for conductance are discussed by Wilsnack (1998).

3.5.3 Canal Sediment Properties

Table 3.5.1 contains the available hydraulic conductivity data for the canal sediments. These data suggest that variations of several orders of magnitude are possible. Initially, all canal reaches were assigned a sediment hydraulic conductivity value of 1.0 feet/day but were varied between 0.01 and 10 feet/day during the calibration process.

The thickness of the bottom sediment bed can typically range from 1 to 5 feet, based on comparisons of surveyed and as-built canal cross sections. Each canal reach was initially assigned a sediment bed thickness of 1 - 3 feet, depending on the age, location and operational characteristics of the channel. These depths were adjusted where necessary during the calibration process.

Although the side walls of the conceptual canal cross section discussed previously are in direct hydraulic contact with the aquifer, it is expected that some head loss should occur in reality with canal - aquifer interactions through the side walls. To account for this, a side-wall sediment layer 0.01 inches thick was initially assigned to all of the canal reaches and was increased in thickness, where appropriate, during the calibration process. As expected, canal reaches that recharge the aquifer were often assigned larger sediment thicknesses in order to account for plugging of the side-walls.

3.5.4 Geometric Cross Sectional Properties

Estimates of the bottom elevation, bottom width and side slopes of the various canal reaches were used to determine canal wetted perimeters for each stress period. Additionally, the bottom elevation data were used to identify those canal reaches that penetrate more than one model layer and apportion the total conductance between the layers penetrated. Sources of data for these canal properties included as-built drawings, surveys and design specifications. In some cases, missing bottom width data were estimated from aerial photographs. For additional details, see Wilsnack (1995) and Wilsnack (1993).

3.5.5 Canal Stages

Mean daily stages for each canal reach were needed not only for direct input to the River and Drain packages but also to compute the required conductance values. Canal stages were based on the available stage monitoring stations shown in figure 3.5.2. Where a monitoring station location coincides with a structure, both head water and tail water elevation data were usually available.

The manner in which stages were assigned to canal reaches was varied and somewhat subjective. For each canal reach bounded between two stations (figure 3.5.2), the hydraulic grade line profile was typically estimated in a stair-step fashion where an upstream portion of the canal reach is assigned data from the station located at the upstream end, a downstream portion of the canal reach is assigned stage data from the station located at the downstream end, and the remaining portion of the canal reach in between is assigned the average of the two data values. In contrast, the hydraulic grade line profile in some canal reaches was assumed flat and based on the nearest stage station. For example, certain canals classified as drains were assigned constant hydraulic grade line elevations equal to their downstream control elevations.

Table 3.5.1. Hydraulic Conductivity Data for Canal Sediments

K_s (ft/day)	Test Method	Source
0.03	core / permeameter	Chin (1990)
0.12	Computed from canal stage and flow measurements	Miller (1978)
0.98	core / laboratory	Miller (1978)
9.80	core / laboratory	Miller (1978)

3.6 Quarries

Two types of quarries exist within the model domain. The first includes only those quarries excavated by the limestone mining industry (figure 2.3.1). Using a modified version of the Lake package (Nair and Wilsnack, 1998; Counsel, 1998), these mining quarries were represented in the model as deep pits with vertical walls that are in direct hydraulic connection with the surrounding aquifer. Additionally, these mines were characterized as having horizontal bottoms that are buffered from the aquifer by a bed of fine sediments. The sediment bed was assumed to be 3 feet thick with a hydraulic conductivity of 0.1 ft/day. Information on quarry depths was obtained from representatives of the mining industry.

During a model simulation, water is transferred either to or from each quarry depending on the difference between ground water levels in the surrounding aquifer and the quarry stage. As part of the solution scheme, lake stages are solved for implicitly along with the head in each active cell (Nair and Wilsnack, 1998). This differs from the solution scheme employed by the previous version of the Lake package (Counsel, 1998) where lake stages from the previous time step were used in the solution scheme for the current time step. For additional information on the functionality of the Lake package, see Nair and Wilsnack (1998), Counsel (1998) and Counsel (1999).

The second type of quarry accounted for in the model consists of borrow areas associated with urban development projects. In contrast to the limestone mining quarries, these lakes are incorporated into the model by appropriately modifying the aquifer properties of the cells containing the lakes. Due to the number, sizes and aerial distribution of these lakes within the model domain, including them in the Lake package along with the limestone mining quarries would make model simulations more burdensome without necessarily improving the usefulness of model results. For modeling purposes, these lakes were characterized in the same manner as the limestone mining quarries. However, they were all assumed to lie entirely within the top aquifer layer of the model. Values of hydraulic conductivity, vertical conductance and specific yield for model cells partially or wholly contained within these lakes were proportionately adjusted to reflect the presence of the open aquifer volume (K = 25,000 ft/day; Vcont = 0.033 ft/day; Sy = 1.0) and bottom sediment bed. This type of approach was successfully applied to the limestone mining quarries in a previous investigation by Wilsnack, et.al. (1997).

3.7 Rainfall Recharge and Evapotranspiration

MODFLOW's ET and Recharge packages were used to simulate the processes of evapotranspiration and rainfall recharge. These packages required the following input:

- recharge rate
- potential evapotranspiration (PET) from the saturated zone
- evapotranspiration surface
- extinction depth
- IEVT and IRCH arrays

The recharge rate and PET rates were calculated using the same AFSIRS based approach employed by the South Florida Water Management Model (Brion, et.al., 1999). This methodology is based on a daily mass balance of the unsaturated zone that quantifies infiltration to and ET from the water table. For more information on this approach, the reader is referred to Brion, et.al (1999), and Restrepo and Giddings (1994).

Daily rainfall data at station locations (figure 3.7.1) were interpolated to cell locations using a TIN based approach in order to avoid abrupt changes in rainfall between model cells. Daily reference ET values, on the other hand, were determined using data obtained from the closest available station. Stations containing data needed to determine reference ET were located at Hialeah, MIA, Miami Beach, and Fort Lauderdale. Additionally, the ET surface elevations and extinction depths were constructed using the shallow and deep root zone depths associated the different land use types. The ET surface was set at land surface elevation minus the shallow root zone depth while the extinction depth was assumed to be equal to the difference between the shallow and deep root zone depths. The IEVT and IRCH arrays represent the layers to which ET and recharge are to be applied. These arrays were set equal to 1 in areas where the wetland layer is active and 2 elsewhere.

3.8 Water Supply Pumpage

The spatial locations of the public water supply wells in northern Miami-Dade County (figure 2.4.1) were obtained from GPS based surveys conducted by the Miami-Dade Department of Environmental Resources Management (DERM). Well construction information for these wells were also obtained from records maintained by DERM. The permit files submitted to the District by the utilities were reviewed for well construction information on, as well as locations of, most of the wells in southern Broward County.
Daily pumpage from major wellfields within Miami-Dade County was estimated over the 1993-94 period of record. These estimates were based on wellfield operation records maintained by the Miami-Dade WASA along with pump capacities. Estimates of daily pumpage based on these data, however, will generally be too high since head losses incurred within the water distribution system are not taken into account. For this reason, the resulting pumpage rates were reduced during the model calibration process.

Daily pumpage was not estimated over the 1988-89 calibration period of record for any of the public water supply wells or for any wells located within Broward county during either period of record. Instead, information contained in monthly water use reports submitted to the District was used to assign monthly pumpage rates to each water use permit. The resulting mean daily pumpage for each permit was then divided among its wells according to a specified percentage for each well.

3.9 Boundary Conditions

The boundaries of the active model domain were represented through the General Head Boundary (GHB) package. The GHB package simulates head dependent flows and requires the specification of a conductance term and an external head. Figure 3.9.1 depicts the locations of the boundaries. The northern boundary is located along the C-11 canal. The southern boundary is located along portions of the C-1W, C-1N, C-100 and C-100A canals. The western boundary traverses portions of WCA-3A, the L-67A borrow canal, the L-67 extension borrow canal and a portion of the ENP. The eastern boundary coincides with the intercoastal waterway.

The northern, western and southern boundaries were all modeled in essentially the same manner. Active wetland cells along these boundaries were assigned a conductance value of 600,000 ft^2/day while the conductances of the aquifer layers were calculated using a flow length equal to one half of the length of a cell and the hydraulic conductivity of the aquifer. The conductance for a boundary cell is given by:

$$C = \frac{k \cdot t}{250} \tag{3.9.1}$$

where k is the horizontal conductivity of the aquifer and t is the thickness of the cell in the vertical direction. The stages along the northern and southern boundaries were based on the water levels in the canals; while any boundaries located west of the levee system were based on the nearest available measured stages.

The eastern boundary condition is based on monthly-averaged historical tidal data from the USGS Golden Beach monitoring station. Monthly average tidal stages at this station were calculated from 10/01/73 through 2/29/80, the operational period of record for this station (Krishnan and Gove, 1993). In addition, unlike the stages along the other boundaries, the presence of the salt water interface along the eastern boundary necessitated certain corrections to the tidal stages and conductances. First, the concept of equivalent fresh water heads was used to

express the vertical pressure distribution along the boundary in terms of fresh water heads. Equivalent fresh-water heads were calculated using the following formula:

$$H_{eq} = (H_s - L_e)(\gamma_s/\gamma_f - 1) + H_s \tag{3.9.2}$$

where

- H_{eq} = the equivalent freshwater head at the boundary;
- H_s = the tidal stage;
- L_e = the elevation within the aquifer where the equivalent freshwater head is to be applied;
- γ_s = the specific weight of salt water;
- γ_f = the specific weight of fresh water.

In order to avoid large vertical flows at the boundary while mimicking the natural processes at this location, the following scaling factor was applied to the conductance values along the coastal boundary:

$$Sc = \left(\frac{(\mathrm{H_s - L_e})}{(\mathrm{H_s - L_{eb}})} - 1 \right)^2 \cdot 0.1 \tag{3.7.3}$$

where Sc is the scaling factor and L_{eb} is the elevation of the surficial aquifer system base (Restrepo, 1998, personal communication). This scaling factor has the effect of greatly reducing conductances in the deeper layers of the model. Conceptually, this reflects the assumption that the freshwater-saltwater interface is a sharp interface that does not move. Given this, freshwater in the deeper layers of the model must flow up and over this interface and leave the model through the upper layers.

3.10 Initial Conditions

Initial conditions for each of the calibration periods of record were estimated at each model cell using the monitoring sites where data existed on the first day of the period of record in question. An inverse distance weighted technique was applied to these locations to estimate an initial water level at each cell location. Hydrostatic conditions were assumed. Furthermore, this process was carried out separately for model cells located east and west, respectively, of the levee system that isolates WCA 3B and the ENP from the urban areas.

4 Model Calibration

4.1 Objectives

The primary purpose of the history matching effort was to improve the model so that it is capable of replicating, within an acceptable margin of error, historical water levels and canal base flows at monitored locations. This capability should be realized under a range of hydrologic conditions. To accomplish this, two eighteen-month periods of record were selected: January 1, 1988 through June 30, 1989 and July 4, 1993 through December 31, 1994. These periods of record combined reflect hydrologic conditions ranging from dry to very wet. In addition, they contain the dates of each of the two available land use coverages for the model domain (1988 and January, 1994). Moreover, a different canal configuration exists within the northern Lake Belt mining area for each of these time frames. This enhances the diversification of historical stresses imposed on the ground water flow system.

In order to reach a tangible milestone of the calibration process before the required starting date for initial model applications, it was requested that the calibration process be separated into two phases. The first phase, completed prior to initial model applications, only addressed ground water levels and wetland stages in the history matching process. The second phase would include, in addition to water levels, base flows accumulated over selected canal reaches as a calibration target. Water budgets for various subareas of the model domain (e.g. WCA-3B) would also be analyzed during this phase. In general, it is not advisable to disaggregate the history matching process in the manner described since improper adjustments to certain parameters may result whenever base flows to canals are not considered. However, the effects of this on the intended model applications can be minimized if computed ground water levels are primarily used in making model based decisions.

4.2 Sensitivity Analyses

4.2.1 Preliminary Sensitivity Maps

In order to gain an improved understanding of the ground water flow system, a preliminary sensitivity analysis was performed where changes in steady state water table elevations and wetland water levels were examined for each of a series of changes in model input parameters. Changes in computed water levels were examined visually by constructing sensitivity maps (Anderson and Woessner, 1992) for both the wetland and top aquifer layers. The results are summarized qualitatively for the top aquifer layer in tables 4.2.1 and 4.2.2. It should be emphasized that this sensitivity analysis is only preliminary and should be supplemented by a more rigorous type of sensitivity analysis that is conventionally performed during and/or after the calibration phase.

4.2.2 Sensitivity to Initial Conditions

In order to assess the length of time beyond the beginning of the simulation where computed water levels may be sensitive to errors in initial water levels, two additional calibration simulations were performed over each period of record. These additional simulations were identical to the base simulation except that the initial water levels were increased and decreased, respectively, by one foot. The outcomes of all three simulations within each period of record were compared and are presented in appendix D-1 for the wet period of record and in appendix D-2 for the dry period of record. These results suggest that errors in initial conditions could significantly affect computed water levels for approximately the first 4 – 6 months of the simulation at locations in or near wetlands. It also appears that errors in computed water levels would be substantially reduced after the first 2 – 3 months. However, it is doubtful that errors in initial conditions at most locations within the extensive wetland systems will be as large as 1 foot. In contrast, errors of this magnitude could be realized at locations within urban areas where measured water levels are too sparse. Fortunately, computed ground water levels in these areas do not appear to be sensitive to initial conditions after about the first month of the simulation.

Considering all of this, the first two months of each calibration period of record were ignored when computing the calibration statistics for each monitoring site. This should help to minimize the effects of errors in initial conditions on computed water levels without eliminating too large of a portion of each period of record. It is suggested that a detailed error analysis of initial conditions be performed in order to better define the amount of time a simulation should progress before history matching is attempted.

4.3 Steady State Calibration

4.3.1 Objectives

The primary purpose for performing a steady state calibration is to achieve an initial refinement in certain model parameters before commencing the more rigorous transient history matching tasks. In particular, it affords an opportunity to evaluate aquifer parameters other than storage without concern for the types of compensating effects errors in storage can have on errors in other hydrogeologic parameters during a transient simulation. While this may sound advantageous, one must still consider the fact that steady state conditions, in the true sense of the term, are seldom ever realized by a hydrogeologic system for any appreciable length of time. This is especially true within the model domain where both natural and man-made stresses imposed on the surficial aquifer system and wetlands can be highly variable. Nonetheless, a number of approaches can still be employed to formulate a meaningful steady state calibration scheme. Some of these are discussed by Anderson and Woessner (1992). The selected approach was to apply average stresses of each period of record to the model as steady state stresses. Given these conditions, the selected calibration criterion was based on the notion that computed water levels should at least fall within the range of observed water levels and, preferably, closer to the mean than either the maximum or minimum value.

4.3.2 Results

The results of the steady state calibration are provided in figures 4.3.1 and 4.3.2. In particular, these illustrations depict the locations where computed water levels fall within one standard deviation from the mean, beyond one standard deviation from the mean but within the observed range, and outside of the observed range. Additionally, at locations where residuals do not fall within the first category just mentioned, different symbology is used to portray whether the computed water level was above or below the mean value. This is useful for identifying possible biases inherent to the model.

4.4 Transient Calibration

The target criterion for transient residuals at each of the monitored sites was ± 0.5 foot, with ± 1.0 foot considered the maximum acceptable tolerance for initial model application purposes. Calibration of the model was achieved primarily through adjustments to horizontal hydraulic conductivity, canal conductance values and public water supply pumpage. The success of the model in achieving these criteria is summarized in table 4.4.1 for the wet period of record and in table 4.4.2 for the dry period of record. As indicated previously, the first two months were omitted from the statistics to minimize the effects of initial conditions in the results. In addition, the computed, observed and residual hydrographs for all of the monitoring sites are provided in appendix E-1 for the wet period of record and in appendix E-2 for the dry period of record.

It is important to note that the statistics for each gage are based on the measured water level data available at that site within the calibration period of record. As mentioned previously, data only exist over a fraction of the total period of record at certain observation wells, resulting in statistics that may not be indicative of model accuracy over the entire period of record. Furthermore, the measured ground water levels are the daily maximum values (the only ground water levels published by the USGS) at each site and may not always be close to observed end-of-day ground water levels, especially under very wet conditions. In contrast, the model computes water levels at the end of each time step (i.e. day). Additionally, one can generally not expect a finite-difference based model to replicate ground water levels observed in the immediate vicinity of a pumping well due to limitations imposed by the spatial resolution of the model. Similarly, limitations in boundary conditions can affect computed heads at sites located near the boundary.

The history matching of surface water levels at sites within WCA-3B and the ENP was subject to a somewhat different set of limitations. In contrast, measured stages at these sites consist of mean daily values. These are more suitable for comparison with water levels computed at the end of each day since average daily stresses are imposed on the model. Like the observation wells, however, the accuracy of the surveyed measuring point elevations is a concern considering the increased difficulty in determining these elevations at such locations. Perhaps one of the greatest hurdles imposed on the model calibration in wetland areas is the lack of experience in simulating wetland water levels along with ground water levels at a regional scale using the Wetland package. Similar efforts have not been carried out previously or are not documented. This was compounded by the numerical difficulties encountered when attempting to increase hydraulic conductance beyond the values shown in table 3.2.2 and closer to the published values shown in table 3.2.1. The history matching simulation for the 1993-94 period of record was repeated with a maximum value of $K_w = 10^7$ ft^2/day/ft$^\beta$ as compared to the value of 10^6 ft^2/day/ft$^\beta$ previously used for both periods of record. The results at monitoring sites located in or near wetlands are shown in appendix E-1. Although the computed wetland stages for this simulation were generally more accurate, the use of the higher K_w values was more computationally burdensome and resulted in much longer simulation times that would render the model unpractical for its intended applications.

Despite all of these difficulties and limitations, the results suggest that the ability of the model to replicate historical water levels under a variety of conditions is satisfactory. One relatively minor exception to this may exist near the northern end of the Northwest Wellfield during the 1988-89 period of record, where the convergence criterion could not be met for about 6% of the time steps. This was due to numerical difficulties caused by interactions between the northern-most well and an adjacent quarry.

Figures 4.4.1 and 4.4.2 illustrate the spatial distribution of ground water levels for late May, 1989 and mid-November, 1994. Comparing the water levels between these two dates portrays the manner in which the potentiometric surface of the surficial aquifer system can vary between wet and dry hydrologic conditions.

5 Conclusions and Future Improvements

5.1 Model Capabilities and Limitations for Applications

The preceding discussions suggest that the model, in its current state, is adequate for comparative type analyses where water level based performance measures for various water supply alternatives are compared in order to select the most appropriate alternative(s) to undergo more detailed analyses. The locations of such performance measures should not be near the model boundaries or in the vicinity of large, localized stresses. In particular, it should be emphasized that the eastern boundary of the model is based on a simplistic representation of the saltwater/freshwater interface within the surficial aquifer system. The characteristics, position and movement of this interface are all based on complex factors and principles (e.g. density-driven flow) that cannot be readily incorporated into a ground water flow model that only accounts for freshwater flow. Consequently, the model cannot directly support any performance measures that relate to, or are contingent upon, the shape, position or movement of the saltwater wedge that, in reality, constitutes the eastern boundary of the ground water flow system.

It is suggested that only water levels be used to formulate performance measures since all of the history matching work completed so far has been limited to water levels. Ground water flows and canal base flows computed by the model should be used with caution. In either case, it is recommended that the effect of uncertainties in model input on model-based alternative comparisons be assessed prior to making any final decisions regarding alternative selections.

5.2 Future Improvements

Certain improvements to the model are recommended in order to enhance its ability to support future applications. Such enhancements should include, but not necessarily be limited to, the following:

1. The resolution of any outstanding data quality issues related to measured water levels (e.g. correcting errors in measuring point elevations);

2. A continuation of the calibration process (see previous discussion) that addresses canal base flows and water budgets (the use of automated techniques, such as those inherent to MODFLOWP (Hill, 1991) and UCODE (Poeter and Hill, 1998), should be considered);

3. Incorporating an improved representation of the saltwater-freshwater interface located at the eastern boundary;

4. A sensitivity analysis of calibrated model results;

5. The use of improved solver packages that are better suited to the types of nonlinear features and large, ill-conditioned matrices inherent to the model;

6. The incorporation of additional surface water modules that would allow canal stages and rainfall recharge to be simulated by the model.

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Appendix A: GIS Database

The specific components of the GIS database used to support model construction can be viewed by accessing the associated ARCVIEW project. Discussions of the primary components are provided below.

A.1 General Features

Using the GIS software ARC/INFO, a GIS database was constructed for the purpose of storing, editing, querying and displaying all of the spatial data required to construct the model. Except for the additions and enhancements needed to support the new features of the current version of the model, the design and contents of this GIS database are essentially the same as those of the GIS database used to construct the previous version of the model. These are described in detail by Wilsnack and Nair (1998). Table A.1.1 provides an overview of the predominant features of the current GIS database.

Table A.1.1. Major GIS Database Features

Model Feature	ARC/INFO Feature Class	Attribute Storage
Wetland flow anisotropy Wetland diversion cells IBOUND	Region subclass	region attribute table
land use model grid quarries	Polygon	polygon attribute tables look-up (INFO) tables
canals outer boundary	Route subclass	continuous events
Stage and flow gages wells (all types) land surface elevation	Point	point attribute tables look-up (INFO) tables
Land surface elevation All matrix-type input	n/a (GRID)	floating point or integer GRIDS

A.2 Coverages of Aquifer Properties

A.2.1 Geologic Control Wells

A point coverage of the geologic control wells shown in figure 3.2.2 was constructed and used to store the estimated hydraulic conductivity ranges as well as the bottom elevations of the various lithologic units. The resulting coverage was used to construct point coverages of horizontal hydraulic conductivity and vertical conductance for each relevant model layer.

A.2.2 Hydraulic Conductivity

A point coverage and a raster coverage (GRID) of mean horizontal hydraulic conductivity were both constructed for each model layer. Similarly, a Vcont point coverage and GRID for each relevant model layer were also constructed. Each point coverage was derived from the geologic control well coverage where the Inverse Distance Weighted function of the ARC/INFO GRID module was used to construct the raster coverages from the respective point coverages. Considering the heterogeneous nature of the surficial aquifer system, it was felt that this spatial interpolation technique was a suitable choice since it results in interpolated values that are somewhat biased towards the closest measured values. These raster coverages were modified using map algebra techniques to account for the presence of the urban development lakes (see section A.7). The resulting raster coverages of hydraulic conductivity were capped at 25,000 ft/day for numerical stability purposes.

A.2.3 Storage and Specific Yield

Specific yield for model layers 1 and 2 assumed the constant values indicated previously except in cells containing urban development lakes. At these locations, map algebra techniques were used to increase the value of specific yield to account for the extra storage created by the lakes. In particular, cells contained wholly within a lake were assigned a value of 1.0 for specific yield.

A GRID depicting the storage coefficient was only created for layer 2 since it did not vary within the other layers due to their constant thicknesses. The storage coefficient GRID for layer 2 was constructed using map algebra techniques to account for the differences in the thickness of layer 2 between the wetland and urban areas.

A.3 Coverages of Wetland Properties

A.3.1 Wetland Layer Elevations

As discussed previously, the bottom elevation of the wetland layer was set at 0 feet NGVD where extensive wetlands exist and at land surface elsewhere (figure 3.2.1). A raster coverage depicting these layer bottom elevations was constructed from the land surface elevation GRID (section A.10) and the layer 1 IBOUND GRID using Boolean based map algebra techniques afforded by the ARC/INFO GRID module.

A raster coverage of ZBOTT, a parameter of the wetlands package that depicts land surface elevation within the wetlands, was initially set equal to land surface elevation. It was later capped at 7.5 feet NGVD to remove local variations that lead to numerical instabilities.

A.3.2 Other Properties

Table A.1.1 lists those wetland properties that are included in the GIS database as Region subclasses of the model grid coverage. In addition, techniques similar to those used to construct coverages of horizontal hydraulic conductivity and Vcont were applied to the geologic control well coverage to construct both point and raster coverages for HYMUC, VHYMUCR and VHYLY2R. Minimum values were latter applied to the GRIDS for numerical stability purposes.

A.3.3 Conversion of Coverages to the Wetland Package Input Data Set

The primary input data set to the Wetland package contains records depicting the address and hydraulic conductance of each wetland cell. These records were constructed by first converting the IBOUND region subclass for the wetland layer to a polygon coverage. This coverage, the model grid coverage and the land use coverage were then combined through an overlay process. The resulting coverage attribute table was joined to the look-up INFO table relating land use to hydraulic conductance. This final attribute table was used to generate a text file containing the required information for each wetland cell.

A.4 Canals

The locations of the canal centerlines were stored in the GIS database as a line coverage with a route subclass. Figure 2.2.1 shows the canals that were included in the model. The route system along with the events shown in table A.4.1 were used to assign the necessary attributes to each canal. Techniques similar to those described by Wilsnack (1998) were used to construct the River and Drain package input data sets from these canal attribute events along with the stage data.

A.5 Land Use

A separate vector coverage of land use was used to support each of the calibration periods of record. One reflects conditions around 1988 while the second coverage depicts land uses that existed around January, 1994. Furthermore, both utilize the District's earlier land use classification system (level 3). Certain deviations from this, however, exist within portions of the 1994 land use coverage that correspond to the Pennsuco wetlands and the Lake Belt mining area. Customized land use codes depicting various degrees of Melaleuca infestation in these areas were derived from a land cover study by EAS Engineering (1996) and incorporated into the coverage. The land use coverages were used to construct the ET surface arrays, the extinction depth arrays and the input data sets for the Wetlands package. To accomplish this, two look-up INFO tables were used: one depicting the relationship between land use and root zone depths and another relating land use to the wetland hydraulic conductance coefficient. ET surface and

Table A.4.1. Events used to associate canal attributes with the canal route system.

Attribute	Event Type	Comments
model cell address	Linear	Constructed through overlay of the route system onto the model grid coverage
bottom elevation	Continuous	Used for layer assignments
bottom width	Continuous	
side slope	Continuous	
Bottom sediment bed thickness	Continuous	Subject to adjustment during the calibration process
Side wall sediment layer thickness	Continuous	Subject to adjustment during the calibration process
sediment hydraulic conductivity	Continuous	Subject to adjustment during the calibration process
canal classification	Continuous	River, Drain or GHB
Stage station assignment	Continuous	

extinction depth grids were constructed in the manner described by Wilsnack and Nair (1998). The development of the input data sets to the Wetland module was discussed in section A.3.3.

A.6 Public Water Supply Wells

A point coverage of the public water supply wells discussed previously was constructed to represent the well locations in the GIS database. The available well construction data were stored in the attribute table for this coverage. The techniques used to construct the Well package input data set from this coverage are discussed in Wilsnack and Nair (1998).

A.7 Quarries

Coverages of the 1988 and January, 1994 limestone mining quarry configurations were derived from each of the above land use coverages. For modeling purposes, each of these coverages was modified so that the quarry planforms were rectilinear and aligned with cell boundaries. These latter coverages were used to construct the input data sets to the Lake package.

A coverage of the urban development lakes was also derived from the land use coverages. This coverage was combined with the model grid coverage through an overlay process in order to determine the fraction of each cell's area that is occupied by these lakes. These results were contained in a raster coverage that was used to modify the hydraulic conductivity and vertical conductance coverages so as to account for the presence of these lakes.

A.8 Outer Boundary

The boundaries of the active model area are stored in a line coverage with a route system (figure 3.9.1). Similar to the canal route system, this boundary route system is associated with continuous events that designate the stage monitoring stations whose data are used to define the stage along each section of the boundary. Other events associated with this route system include linear events representing cell addresses and the hydraulic conductivity of each model layer. These events were constructed through overlays of the route system onto relevant polygon coverages and were used to compute the boundary conductances as discussed previously. The input data set to the General Head Boundary package was constructed from these events using a procedure that is similar to the one used to construct input data sets to the River and Drain packages.

A.9 Model Grid Coverage

A polygon coverage with the geographic limits shown in figure 3.1.1 was constructed in order to represent the model grid in the GIS database. Cell attributes stored in the attribute table were limited to row and column numbers along with a multiplier term for hydraulic conductivity. All other model parameters stored within the grid coverage were included as Region subclasses (table A.1.1).

A.10 Land Surface Digital Elevation Model (DEM)

Initially, a separate point coverage of each of the data sources shown in table 3.4.1 and figure 3.4.1 was created. These point coverages were then combined into a single point coverage using the APPEND command. Finally, the DEM was created in the GRID module using the Inverse Distance Weighting interpolation function. The IDW method was chosen since the points are well distributed spatially throughout the modeled area and the sampling of points was fairly dense especially in WCA-3B, the Pennsuco wetlands and the ENP. Moreover, the IDW method does not create ridges or valleys in the DEM and the resulting interpolated values cannot exceed the input point values. Also, an exponent of 2 was specified for the IDW interpolation method which emphasizes the nearby points. This may be advantageous within the urban areas where land surface elevations can be highly variable. Conversely, the choice on the exponent is less consequential in the wetland areas where data tend to be more abundant and less variable.

Appendix B: Hydrologic Database

B.1 Rainfall and Potential Evapotranspiration

Daily rainfall and PET data for the calibration periods of record were extracted from the hydrologic database used to support the South Florida Water Management Model (Brion, et. al., 1999). The supporting documentation for this model provides information on available rainfall and PET stations within the model domain.

B.2 Canal Stages

Mean daily canal stages were compiled, where available, over the calibration periods of record for each of the monitoring stations shown in figure 3.5.2. Most of these data were obtained from DBHYDRO while some were extracted directly from the USGS ADAPS database. As expected, numerous data gaps existed within each period of record at a number of these stations. Since continuous time series were needed to generate model input data sets, steps were taken to fill in these gaps using the most appropriate of the following techniques:

- correlation with other nearby stations;
- compute mean daily stages from available break point data;
- estimate mean daily stages from daily staff gage readings;
- substitute representative historical time series or average values for the missing values;
- estimate missing stages over the data gap using linear interpolation.

B.3 Ground Water Levels and Wetland Stages

Historical water level data were compiled for each of the monitoring stations shown in figures B.3.1 and B.3.2. The ground water levels represent maximum daily values while the surface water data (i.e. water levels in wetlands) consist of mean daily stages. Both types of data were used for history matching purposes. Also, data were not continuously available at each site. For a number of stations, data were only available over several months.

The measuring point elevations of a selected set of observation wells were resurveyed by District staff and compared to the elevations published by the USGS. These comparisons are provided in table B.3.1. According to USGS staff (Scott Prinos, 1999, personal communication) possible causes of these discrepancies would include, but not necessarily be limited to, the following:

- undocumented structural changes to the monitoring apparatus that would change the measuring point elevation;
- common survey errors such as erroneous measurement readings;
- a faulty datum plan where different benchmarks using in the surveys were never tied together.

Table B.3.1. Discrepancies in surveyed measuring point elevations for selected observation wells.

Site Name	SFWMD measuring point elevation (1999) (feet NGVD)	USGS measuring point elevation (1998) (feet NGVD)	Comments
G-968	10.67	10.87	
G-3567	9.245	10.14	
G-3259A	8.03	7.43	
G-3253	10.91	9.29	
G-3565	11.75	11.82	
G-551	10.17	10.12	
G-3560	12.01	10.16	USGS reports indicate frequent changes in the published measuring point elevation for this well.

Appendix D-1

This appendix contains the individual hydrographs that depict the sensitivity of the model to initial conditions over the 1993-94 period of record. These hydrographs can be viewed for any of the gages listed below by clicking on the associated hypertext link.

3B-SE_B	F-179	F-239	F-291	F-319	F-45
G-1074B	G-1166	G-1223	G-1224	G-1225	G-1226
G-1359	G-1368A	G-1473	G-1487	G-1488	G-1636
G-1637	G-2034	G-2035	G-2495	G-3	G-3073
G-3074	G-3253	G-3259A	G-3264A	G-3327	G-3328
G-3329	G-3439	G-3465	G-3466	G-3467	G-3473
G-3551	G-3552	G-3553	G-3554	G-3555	G-3556
G-3557	G-3558	G-3559	G-3560	G-3561	G-3562
G-3563	G-3564	G-3565	G-3566	G-3567	G-3568
G-3570	G-3571	G-3572	G-551	G-553	G-580
G-618	G-852	G-855	G-968	G-970	G-972
G-973	G-975	G-976	NESRS1	NESRS2	NESRS3_B
S-18	S-19	S-68	SHARK.1_H		SITE_34
SITE_71	SITE_76				

Appendix D-2

This appendix contains the individual hydrographs that depict the sensitivity of the model to initial conditions over the 1993-94 period of record. These hydrographs can be viewed for any of the gages listed below by clicking on the associated hypertext link.

3B-SE_B	F-179	F-239	F-291	F-319	F-45
G-1074B	G-1166	G-1222	G-1223	G-1224	G-1225
G-1226	G-1368A	G-1472	G-1473	G-1487	G-1488
G-1636	G-1637	G-2034	G-2035	G-3	G-3074
G-3253	G-3259A	G-3264A	G-3327	G-3328	G-3329
G-3439	G-3465	G-3466	G-3467	G-551	G-553
G-580	G-596	G-618	G-852	G-855	G-858
G-968	G-970	G-972	G-973	G-974	G-975
G-976	NESRS1	NESRS2	NESRS3_B		S-18
S-19	S-68	SHARK.1_H			

Appendix E-1: Calibration Results

These figures portray the computed, measured, and residual hydrographs for each well, for the 1993-94 period of record. These hydrographs can be viewed for any of the gages listed below by clicking on the associated hypertext link.

3B-SE_B	F-179	F-239	F-291	F-319	F-45
G-1074B	G-1166	G-1223	G-1224	G-1225	G-1226
G-1359	G-1368A	G-1473	G-1487	G-1488	G-1636
G-1637	G-2034	G-2035	G-2495	G-3	G-3073
G-3074	G-3253	G-3259A	G-3264A	G-3327	G-3328
G-3329	G-3439	G-3465	SITE_76	G-3466	G-3467
G-3473	G-3551	G-3552	G-3553	G-3554	G-3555
G-3556	G-3557	G-3558	G-3559	G-3560	G-3561
G-3562	G-3563	G-3564	G-3565	G-3566	G-3567
G-3568	G-3570	G-3571	G-3572	G-551	G-553
G-580	G-618	G-852	G-855	G-968	G-970
G-972	G-973	G-975	G-976	NESRS1	NESRS2
NESRS3_B		S-18	S-19	S-68	SHARK.1_H
SITE_34	SITE_71				

Appendix E-2: Calibration Results

These figures portray the computed, measured, and residual hydrographs for each well, for the 1988-89 period of record. These hydrographs can be viewed for any of the gages listed below by clicking on the associated hypertext link.

3B-SE_B	F-179	F-239	F-291	F-319	F-45
G-1074B	G-1166	G-1222	G-1223	G-1224	G-1225
G-1226	G-1368A	G-1472	G-1473	G-1487	G-1488
G-1636	G-1637	G-2034	G-2035	G-3	G-3074
G-3253	G-3259A	G-3264A	G-3327	G-3328	G-3329
G-3439	G-3465	G-3466	G-3467	G-551	G-553
G-580	G-596	G-618	G-852	G-855	G-858
G-968	G-970	G-972	G-973	G-974	G-975
G-976	NESRS1	NESRS2	NESRS3_B		S-18
S-19	S-68	SHARK.1_H			

Appendix E.3: Sensitivity of Wetland Stages to K_w

Listed below are the 1993-94 monitoring sites located in or near wetlands. The water level hydrographs provided here represent the same hydrographs as in appendix E.1 except that they reflect the use of a higher maximum K_w value of $1x10^7$. The following figures portray these computed hydrographs as well as their corresponding measured and residual hydrographs. For comparative purposes, the corresponding computed water level hydrographs provided in appendix E-1 are shown as well.

3B-SE_B	G-1488	G-3551	G-3559	G-618
G-968	G-972	G-975	NERSR1	NESRS2
NESRS3_B	SHARK.1_H		SITE_34	SITE_71
SITE_76				